

Low-Light-Shift Cesium Fountain Without Mechanical Shutters

Light shift is reduced by a combination of detuning and attenuation.

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A new technique for reducing errors in a laser-cooled cesium fountain frequency standard provides for strong suppression of the light shift without need for mechanical shutters. Because mechanical shutters are typically susceptible to failure after operating times of the order of months, the elimination of mechanical shutters could contribute significantly to the reliability of frequency standards that are required to function continuously for longer time intervals.

With respect to the operation of an atomic-fountain frequency standard, the term "light shift" denotes an undesired relative shift in the two energy levels of the atoms (in this case, cesium atoms) in the atomic fountain during interrogation by microwaves. The shift in energy levels translates to a frequency shift that reduces the precision and possibly accuracy of the frequency standard. For reasons too complex to describe within the space available for this article, the light shift is caused by any laser light that reaches the atoms during the microwave-interrogation period, but is strongest for near-resonance light. In the absence of any mitigating design feature, the light shift, expressed as a fraction of the standard's frequency, could

be as large as $\approx 2 \times 10^{-11}$, the largest error in the standard.

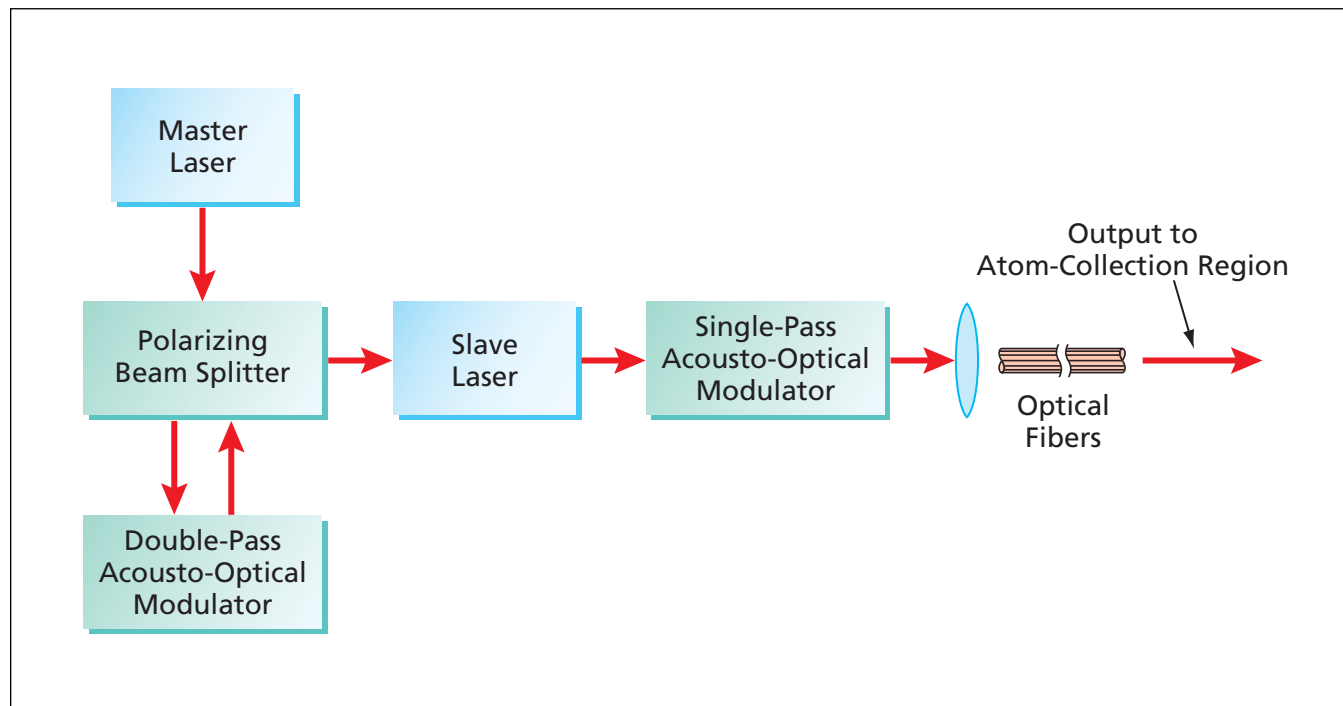
In a typical prior design, to suppress light shift, the intensity of laser light is reduced during the interrogation period by using a single-pass acousto-optic modulator to deflect the majority of light away from the main optical path. Mechanical shutters are used to block the remaining undeflected light to ensure complete attenuation. Without shutters, this remaining undeflected light could cause a light shift of as much as $\approx 10^{-15}$, which is unacceptably large in some applications.

The new technique implemented here involves additionally shifting the laser wavelength off resonance by a relatively large amount (typically of the order of nanometers) during microwave interrogation. In this design, when microwave interrogation is not underway, the atoms are illuminated by a slave laser locked to the lasing frequency of a lower power master laser. The locking is achieved by injecting a small amount of master laser light into the slave laser. This light is injected via a polarizing beam splitter after passing through a double-pass acousto-optic modulator (see figure). The output of

the slave laser is then sent through the single-pass acousto-optic modulator mentioned above to optical fibers that, in turn, feed the light to the collection region of the atomic fountain.

During microwave interrogation, the radio-frequency power applied to the double-pass acousto-optic modulator is turned off in order to cut off the injection light and detune the slave laser to its free-running wavelength, which is typically nanometers away from the resonant master laser. Even in the absence of other measures, this tuning away from resonance reduces the light shift by about four orders of magnitude. Further cutting the radio-frequency power to the single-pass acousto-optic modulator causes attenuation of the slave-laser output beam. It has been verified experimentally that this combination of frequency shift and attenuation reduces the light shift to $< 10^{-15}$, and it has been estimated that the resultant shift could be as low as 2×10^{-19} .

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Laser Illumination of Atoms in the collection region of an atomic fountain is shifted away from the resonance frequency (by use of the double-pass acousto-optical modulator) and attenuated (by use of the single-pass acousto-optical modulator) during microwave interrogation.